

Review on Battery Pack Technologies for Electric Vehicles

Mr. Ritesh Kumar Rajan¹, Dr. I. A. Khan²

¹Mechanical Engineering & Priyadarshini College of Engineering

²Mechanical Engineering & Priyadarshini College of Engineering

Abstract - In an EV system, the battery pack is the single most important part affecting the driving range, charging capability, and safety and longevity of the EV. With advancements in lithium-ion battery technology, battery thermal management systems, and battery pack designs, there have been major improvements in the performance and efficiency of EVs. In this paper, a brief overview on battery technology, battery cell design, battery thermal management, safety considerations, and future trends in EV battery packs has been provided. New technologies such as solid-state batteries, Artificial Intelligence enabled BMS, and structural battery packs have also been covered.

Key Words: Electric Vehicle, Battery Pack, Lithium-Ion Battery, Thermal Management System, Battery Management System, Thermal Runaway.

1. INTRODUCTION

The increasing demand for sustainable transportation has accelerated the development of electric vehicles worldwide. The battery pack serves as the primary energy storage system and typically contributes approximately 30–40% of the total vehicle cost [1]. Therefore, improving battery performance, safety, and energy density remains one of the major research priorities in electric mobility.

A typical EV battery pack consists of battery cells, modules, electrical interconnections, cooling systems, protective structures, and Battery Management Systems (BMS) [2]. These components must operate together to provide reliable and safe performance under varying operating conditions.

2. Lithium-Ion Battery Technology

Lithium-ion batteries have become the dominant energy storage technology for electric vehicles because of their high energy density, long cycle life, and low self-discharge characteristics [3]. Commercial EV batteries mainly utilize Lithium Iron Phosphate (LFP), Nickel Manganese Cobalt (NMC), and Nickel Cobalt Aluminum (NCA) chemistries depending on application requirements [4].

LFP batteries provide excellent thermal stability and long service life, whereas NMC and NCA batteries offer higher energy density suitable for long-range vehicles [5]. Recently, solid-state batteries have emerged as promising alternatives due to their potential for improved safety and higher energy density resulting from the use of solid electrolytes instead of flammable liquid electrolytes [6].

2.1 Comparison of Major Lithium-Ion Battery Chemistries

The selection of battery chemistry plays a crucial role in determining the energy density, cycle life, safety, charging capability, and cost of an electric vehicle battery pack [1], [2]. Among commercially available lithium-ion technologies, Lithium Iron Phosphate (LFP), Nickel Manganese Cobalt (NMC), and Nickel Cobalt Aluminum (NCA) are the most widely adopted chemistries in modern EV applications [3].

LFP batteries exhibit excellent thermal stability, long cycle life exceeding 4000 charge-discharge cycles, and relatively low manufacturing costs due to the absence of expensive cobalt materials [4], [5]. However, their lower energy density generally limits their application in long-range electric vehicles [4].

NMC batteries provide a balanced combination of energy density, power capability, and durability. The adjustable nickel, manganese, and cobalt composition allows manufacturers to

optimize battery characteristics according to vehicle requirements [3], [5]. Consequently, NMC batteries are extensively used in passenger electric vehicles because of their favorable compromise between energy density and safety [3]. NCA batteries offer among the highest energy densities in commercial lithium-ion batteries and are therefore preferred for premium long-range electric vehicles [5]. However, their relatively lower thermal stability requires advanced thermal management systems and sophisticated battery management strategies to ensure safe operation [6].

3. Battery Cell and Pack Configurations

Electric vehicle battery packs primarily utilize cylindrical, prismatic, and pouch cell formats see fig 3.1.1. Cylindrical cells provide excellent mechanical strength and manufacturing maturity, while prismatic and pouch cells offer improved packaging efficiency and higher pack-level energy density [7]. Conventional battery systems use module-based architectures in which cells are assembled into modules before pack integration. Recent developments such as Cell-to-Pack (CTP) and Cell-to-Chassis (CTC) technologies eliminate intermediate structures and improve energy density while reducing manufacturing complexity and weight [8].

3.1 Battery Cell Formats

Battery cells used in electric vehicles are commonly classified into cylindrical, prismatic, and pouch configurations [7]. The selection of cell geometry directly influences thermal performance, manufacturing complexity, packaging efficiency, and crashworthiness [7], [8].

Cylindrical cells provide excellent mechanical strength and manufacturing maturity, making them suitable for high-volume production [7]. Prismatic cells improve packaging efficiency and reduce the number of electrical interconnections required within the battery pack [8]. Pouch cells offer high gravimetric energy density because of their lightweight packaging structure but require additional mechanical support to control swelling during operation [8].

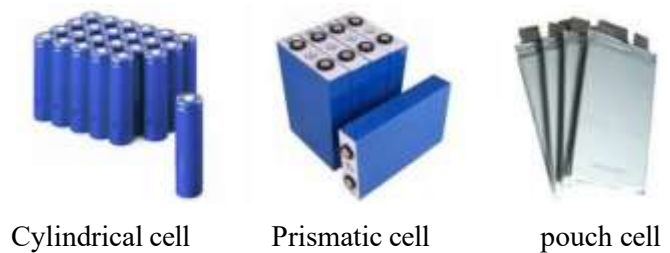


Fig 3.1.1 - Battery Cell Formats

4. Battery Thermal Management System

Battery temperature significantly affects battery performance, aging behavior, charging capability, and operational safety [9]. Excessive temperatures may accelerate capacity degradation and increase the risk of thermal runaway events.

Air cooling remains one of the simplest and most economical thermal management methods for EV battery packs. Natural convection cooling is suitable for low heat generation applications, whereas forced air cooling using fans significantly improves heat dissipation and temperature uniformity within the battery pack [10].

Although air cooling systems are lightweight and inexpensive, their cooling capability is limited under fast charging and high discharge conditions. Consequently, modern high-performance EVs increasingly employ advanced liquid cooling systems to maintain safe operating temperatures [11].

4.1 Battery Pack Architectures

Traditional battery packs employ a module-based design in which multiple cells are assembled into modules before integration into the battery pack [9]. Although this architecture improves serviceability and maintenance, it introduces additional structural components that reduce pack-level energy density [9].

Recent developments such as Cell-to-Pack (CTP) and Cell-to-Chassis (CTC) technologies eliminate intermediate structures and directly integrate cells into the battery pack or vehicle chassis [10]. These approaches improve volumetric utilization, reduce weight, and simplify manufacturing processes while increasing vehicle range [10], [11].

5. Safety and Battery Management Systems

Safety is a critical consideration in battery pack design. Mechanical damage, overcharging, internal short circuits, and elevated temperatures may lead to thermal runaway and catastrophic battery failures [12].

Battery Management Systems continuously monitor cell voltage, current, and temperature to estimate State of Charge (SOC) and State of Health (SOH) while protecting the battery from unsafe operating conditions [13]. Recent advances in artificial intelligence and machine learning have significantly improved fault diagnosis and predictive maintenance capabilities in modern BMS technologies [14].

5.1 Thermal Runaway and Safety Considerations

Thermal runaway represents one of the most critical safety challenges in lithium-ion battery systems [12]. It occurs when heat generated inside the battery exceeds the rate of heat dissipation, resulting in uncontrollable temperature rise and possible fire or explosion [12], [13].

Common causes of thermal runaway include internal short circuits, mechanical deformation, overcharging, manufacturing defects, and exposure to elevated temperatures [12]. Modern Battery Management Systems continuously monitor cell voltage, temperature, and current to detect abnormal conditions and initiate protective actions [13], [14].

Several international standards, including ISO 26262 and UN ECE R100, establish safety requirements for electric vehicle battery systems, including vibration resistance, thermal shock testing, overcharge protection, and crashworthiness evaluation [15].

6. Future Trends and Challenges

Future battery research focuses on improving energy density, reducing charging times, increasing safety, and lowering manufacturing costs. Solid-state batteries, wireless BMS, and structural battery packs are expected to play important roles in next-generation electric vehicles [15].

Battery recycling and second-life applications are also becoming increasingly important for achieving sustainable and environmentally responsible transportation systems [16].

3. CONCLUSIONS

Battery packs are the core technology enabling the widespread adoption of electric vehicles. Advances in battery chemistry, thermal management systems, pack architectures, and intelligent battery management systems have significantly improved vehicle range, safety, and reliability. Nevertheless, challenges associated with thermal management, degradation, charging speed, and sustainability continue to motivate further research. Emerging technologies such as solid-state batteries and structural battery packs offer promising opportunities for future electric mobility solutions.

ACKNOWLEDGEMENT

The author expresses gratitude to the faculty members at Priyadarshini College of Engineering in Nagpur for their valuable support in conducting this research endeavor.

REFERENCES

1. J. B. Goodenough and K. S. Park, "The Li-ion rechargeable battery: A perspective," *Journal of the American Chemical Society*, vol. 135, no. 4, pp. 1167-1176, 2013.
2. S. Haghbin, M. R. Larijani, M. Zolghadri, and S. H. Kia, "Automotive battery pack standards and design characteristics: A review," *Applied Sciences*, vol. 15, no. 6, 2025.
3. A. Yoshino, "The birth of the lithium-ion battery," *Angewandte Chemie International Edition*, vol. 51, no. 24, pp. 5798-5800, 2012.
4. J. B. Goodenough, K. Mizushima, P. C. Jones, P. J. Wiseman, and M. Koizumi, "Li_xCoO₂ (0 < x ≤ 1): A new cathode material for batteries of high energy density," *Materials Research Bulletin*, vol. 15, no. 6, pp. 783-789, 1980.
5. D. Wang, J. C. Jonathan, Z. Teng, C. Zhang, and S. Samveg, "Quantifying electric vehicle battery degradation from driving versus vehicle-to-grid services," *Journal of Power Sources*, vol. 332, pp. 193-203, 2016.
6. J. Janek and W. G. Zeier, "A solid future for battery development," *Nature Energy*, vol. 1, pp. 16141, 2016.
7. T. Teichert et al., "High-voltage battery pack architectures for EVs," *Energies*, vol. 12, no. 18, p. 3456, 2019.

8. G. Belingardi and A. Scattina, "Battery pack and underbody: Integration in the structure design for battery electric vehicles—Challenges and solutions," *Vehicles*, vol. 5, no. 2, pp. 498-514, 2023.
9. T. M. Bandhauer, S. Garimella, and T. F. Fuller, "A critical review of thermal issues in lithium-ion batteries," *Journal of The Electrochemical Society*, vol. 158, no. 3, pp. R1-R25, 2011.
10. A. Alawi, A. Saeed, M. H. Sharqawy, and M. Al Janaideh, "A comprehensive review of thermal management challenges and safety considerations in lithium-ion batteries for electric vehicles," *Batteries*, vol. 11, no. 7, p. 275, 2025.
11. Y. Lai, W. Wu, and K. Chen, "A compact and lightweight liquid-cooled thermal management solution for cylindrical lithium-ion power battery pack," *International Journal of Heat and Mass Transfer*, vol. 144, 2019.
12. M. A. Roscher, O. Bohlen, and J. Vetter, "Detection of lithium-ion battery failures in automotive applications," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 1, pp. 98-107, 2011.
13. M. Xie, H. Hu, and T. Teichert, "Electrothermal battery pack model for automotive application: Design and validation," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 5, pp. 5678-5689, 2020.
14. Y. Kuang et al., "Artificial intelligence in battery management systems: A review," *IEEE Access*, vol. 9, pp. 29712-29729, 2021.
15. T. Teichert et al., "High-voltage battery pack architectures for EVs," *Energies*, vol. 12, no. 18, p. 3456, 2019.
16. J. T. J. Burd, E. A. Moore, and H. Ezzat, "Improvements in electric vehicle battery technology influence vehicle lightweighting and material substitution decisions," *Applied Energy*, vol. 283, 2021.